INVERTEBRATE DRIFT IN AN AUSTRALIAN URBAN STREAM – DAREBIN CREEK, VICTORIA

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The majority of drift studies in Australia have focused on the invertebrate fauna of relatively undisturbed, upland streams. This study investigated the quantity and composition of invertebrate drift above and below three stormwater drains discharging into Darebin Creek, an urban stream in Melbourne, Victoria and the findings were compared to the stream's benthic fauna.

The stream velocity was significantly higher above the stormwater drains, but the mean drift density was greater at the site below these drains. It appears that the presence of pollutants including sewage, nutrients and heavy metals in the stream may have discouraged invertebrates from exiting the drift to colonise the region downstream of the drains. At many of the benthic sites and in the drift, invertebrates associated with stressed environments such as *Cricotopus* sp. and *Chironomus cloacalis* Martin, 1971 (Diptera: Chironomidae) dominated. While only the relative proportions of taxa were different in the samples collected from the drift and the benthos, the usefulness of sampling drift to assess the instream fauna appears questionable because the origin of the invertebrates entering the drift is not known. Sampling both the drift and benthos can give a more complete assessment of the stream invertebrate fauna.

Key words: Invertebrate, drift, urban streams, Chironomidae, disturbance

THE DOWNSTREAM movement of large numbers of invertebrates in the drift, is a common and natural phenomenon of stream invertebrate communities (Brittain & Eikeland, 1988). According to some researchers drift fauna is not considered distinct from benthic fauna (Brittain & Eikeland, 1988). However, research in large rivers by Benke et al. (1986) and Koetsier & Bryan (1989) showed that the species composition in the benthos was different from that of the drift.

Drift influences benthic community dynamics in two ways. Firstly, the continuous loss of animals into the water column reduces local benthic density, and since some species and class sizes are more prone to drift than others, the composition of the local community is affected. Secondly, the continuous settling out of animals from the drift plays an important colonising role. Thus the influences of drift contribute to a continuous redistribution of benthos along the length of a stream (Townsend & Hildrew, 1976).

Drifting is a temporary event in the lives of benthic invertebrate populations (Brittain & Eikeland, 1988). The reasons for drift are still unclear, although many mechanisms have been proposed. Some of these include: random events such as accidental detachment during flood events; behavioural factors leading to redistribution of organisms in over-populated areas (Hieber et al., 2003); patchy food resources, or high densities of predators (Dimond, 1967; Doeg & Milledge, 1991). It also enables organisms to escape unfavourable physical chemical or biological conditions (Olsen et al., 2007), and gives them the opportunity to colonise new habitats (Brittain & Eikeland, 1988; Holomuzuki, 1996).

The downstream movement of invertebrates is not constant but varies seasonally, from day to day, and even during the course of the day (Graesser & Lake, 1984; Brittain & Eikeland, 1988; Flecker, 1992; Schreiber, 1995a). Drift in temperate regions such as Australia and New Zealand, is often greatest in the summer (Benson & Pearson, 1987; Schreiber 1995a), and at a minimum during the winter (McLay, 1968).

Drift has been shown to be influenced by many factors including the photoperiod, water chemistry, water temperature, suspended sediment, stream velocity and water volume, number of predators present, and life cycle stage (Brittain & Eikeland, 1988; Dudgeon, 1990; Doeg & Milledge, 1991; Holomuzuki, 1996; Olsen et al., 2007).

The fate of drift organisms moving into water of poor quality has not been widely studied. However, it has been speculated that drift-borne insects might die relatively quickly, avoid contaminated water by rapid movement back upstream, or remain in the water column and allow themselves to be carried passively through the polluted zone (Bishop & Hynes, 1969). Normally drift invertebrates do not settle on the substrates of heavily contaminated areas (Bishop & Hynes, 1969; Lake et al., 1977; Swain & White, 1985).

In the Northern hemisphere papers describing drift were first published in the 1920s, whereas the study of drift in Australian streams is comparatively recent. However, there have been a number of studies of invertebrate drift undertaken in Victorian streams by Cadwallader & Eden, (1977), Suter & Williams, (1977), Graesser & Lake, (1984), Doeg & Milledge, (1991), and Schreiber (1988; 1995a).

The majority of Australian drift studies have focused on the fauna of less disturbed, upland streams. There are only two studies that have investigated invertebrate drift in an Australian urban stream (Arthington & Conrick, 1981; Arthington et al. 1982). The studies carried out by Lake et al. (1977), Arthington & Conrick, (1981), Arthington et al. (1982), Swain & White, (1985), and Davies et al., (1994), are the only investigations where invertebrate drift was used to assess the impact of pollution on the instream biota and recolonisation dynamics.

If the benthic invertebrate fauna in an urban stream such as Darebin Creek is affected by habitat modifications and poor water quality as a result of discharges from stormwater drains that at times contained sewage outfalls, it may be expected that the quantity and composition of the drift would exhibit a response. This study investigated the quantity and composition of invertebrate drift above and below three stormwater drains discharging into Darebin Creek and the findings were compared with the stream's benthic fauna recorded by Veenstra-Quah, (2000). The usefulness of sampling invertebrate drift to assess the instream fauna is also discussed.

MATERIALS AND METHODS

Study area

Darebin Creek is a tributary of the Yarra River rising in the Great Dividing Range north of Woodstock. The headwaters of the creek have no canopy cover and are in a paddock that has been cleared for cattle grazing. It flows south through agricultural land (predominantly grazing) and enters the outer reaches of the Melbourne metropolitan area at Epping before discharging into the Yarra River at Fairfield. The catchment area is approximately 119 km^2 (Melbourne Water – Catchment & Drainage, 1998) and the total stream length is approximately 47.5 km.

The Melbourne Trough through which Darebin Creek flows is Silurian-Devonian in origin (Douglas & Ferguson, 1976). The creek rises in Lower Devonian sediments north of Woodstock, flowing through Newer Volcanics basalt to the area east of Wollert, where its course was diverted to the east against Silurian sediments around Quarry Hill. Downstream from this, Darebin Creek continues through a youthful valley with Newer Volcanics basalt on both sides. At Darebin, the creek was again diverted eastward laterally to the basalt, just above its confluence with the Yarra River (Northern Melbourne Waterways Study, 1975). The urban area through which Darebin Creek flows was described in the Northern Melbourne Waterways Study (1975) as having gently undulating topography, with lithology comprising alluvium, outwash, colluvium-gravel, sand, silt and clay.

Increased urbanisation including residential and industrial development in the region has resulted in a need to improve water flow characteristics and drainage. As a consequence of flow management, Darebin Creek has been significantly modified by general realignment and straightening of the watercourse, moulding of the banks to form a trapezoid channel in the 1960s, and removal of obstructions such as large boulders and trees (Thexton, 1986).

Rainfall and discharge over the course of the drift study

The Melbourne Bureau of Meteorology recorded monthly rainfall totals in Epping, and Preston, which are suburbs in the vicinity of the stream reach studied. Discharge data were recorded by Melbourne Water at Ford Street, Ivanhoe, approximately 3.9 km downstream of the benthic site below the drains (Site 6). A minimum monthly discharge of 43.11 ML was recorded in March 1998 (autumn), and a maximum of 159.1 ML was recorded in September 1997 (spring).

Benthic sampling

Darebin Creek is the receiving stream not just for stormwater runoff but also for raw sewage discharging from eleven emergency relief structures (Duke &

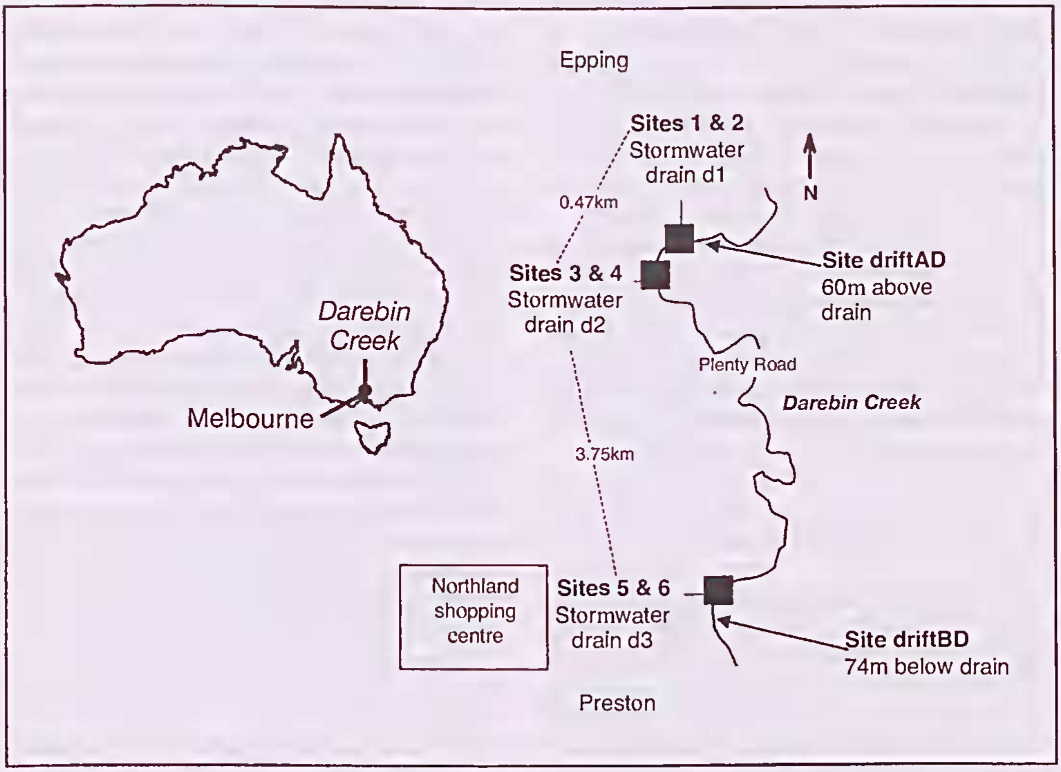

Fig. 1. Location of drift and benthic sampling sites on Darebin Creek in relation to stormwater drains discharging into the stream. Sites 1, 3 and 5 were located above a drain and Sites 2, 4 and 6 below. Not to scale.

Veenstra-Quah, 1997). Emergency relief structures (ERS), are specifically designed outlets installed in sewers which operate during wet weather, when flows are increased by rainfall and exceed the capacity of the system, and during dry weather when equipment or power failures occur. Chemical analysis of sewage in the Darebin Creek Main Relieving Sewer indicated the presence of heavy metals such as, chromium, copper, iron, lead and zinc, as well as high levels of orthophosphate, total nitrogen, and total phosphorus (Duke & Veenstra-Quah, 1997). Apart from the human health risks, the impact of spilt sewage on aquatic ecosystems may jeopardise the long-term health of the waterway.

Freshwater invertebrates have proved to be a useful tool for determining the biological condition of aquatic systems (Resh & McElravy, 1993). In an investigation undertaken by Duke & Veenstra-Quah, (1997) the impact of three stormwater drains with different discharge characteristics on the invertebrate community composition of a section of Darebin Creek, was monitored in 1995.

Three drains discharging into Darebin Creek in the Reservoir region were identified for sampling (Fig. 1) and the benthic and drift sites were defined by the location of these drains. The first drain d1, with Site 1 above and Site 2 below, was considered to be the "control" site for this study as it had similar physical characteristics to the other drains at the downstream sites, but there was no emergency relief structure installed, so no sewage discharging into the creek via this drain. The discharge drain d2, with Site 3 above and Site 4 below, had two emergency relief structures associated with it, and the drain d3, with Site 5 above and Site 6 below, was associated with one emergency relief structure.

Benthic sampling apparatus and procedure

A suction sampler was chosen over the Surber sampler or kick sample because it was independent of current, and has been reported to be quantitatively superior when sampling a variety of substrates (Boulton, 1985). The suction sampler based on Boulton's design, consisted of a square, galvanised iron frame with a thick foam rubber base to ensure a good seal between the substrate and the sampler, a hand operated diaphragm bilge pump, two hoses, a 250 µm collecting net and sample containers. The sampler operator can standardise sampling by disturbing the sediments to a set depth for a set period of time.

On 18 January1995, preliminary sampling at Sites 1, 2, 3 and 6 was undertaken and then all sites were sampled on 21 February 1995 (summer) beginning with Site 6 and proceeding upstream. Five replicates were taken in each area (a total of 30 samples). The same procedures were carried out on the subsequent three sampling trips on 31 May (autumn), 31 August (winter) and 16 November (spring).

Drift sampling sites and procedure

There were two drift sampling sites in Darebin Creek, one 60 m above the first drain – Site driftAD and the other 74 m below the third drain discharge – Site driftBD. A single drift net at both sites was situated near the left bank. Ideally they should have been near the middle of the stream but the rocky substrate limited the choice of location for the placement of the metal stakes used to secure the drift sampler.

The watercourse at Site driftAD can be described as moderately sinuous with the adjacent landuse being housing and recreational. The water depth at this site varied from a minimum depth of 54 cm to a maximum of 80 cm. The stream width at the drift sampling point was 5.8 m and the substrate consisted of 50% fine gravel (particles from 2 to 16 mm in size, which in all cases refers to the median axis diameter), 40% cobbles (particles from 64 to 256 mm) and 10% boulders (particles >256 mm).

The water depth at this site varied from a minimum of 25 cm to a maximum of 53 cm. The stream width was approximately 5.9 m; banks of approximately 60 cm with moderate signs of erosion. The substrate consisted of 60% sand (particles from 0.5 to 2 mm), 20% fine sand/silt (particles <0.5 mm), and 20% cobbles.

The riparian zone at both drift sites was similar, with no canopy cover and an understorey of introduced vegetation. The stream depth was greater at the above drain drift site (driftAD), but the stream width at both sites was very similar. The stream banks were steeper, with more evidence of erosion at the below drains drift site (driftBD).

The drift samplers built for this study were based on a design used by Schreiber (1988). They consisted of two parts: a sheet metal box that could be held stationary in the stream, and 300µm mesh nylon net, 2 m long that could be easily attached and removed without disturbing the benthos upstream of the sampler. To collect a drift sample the net was removed from the metal box and the contents washed into a 500mL container at the end of the net. Drift samples were preserved in the field with either absolute or 95% ethanol and taken back to the laboratory for sorting.

To fix the samplers in the stream (one at each site), the sampling box had a metal frame on either side which slid onto metal stakes that had been hammered into the streambed at the two sites and remained throughout the study period.

Drift organisms are known to exhibit diel periodicity – recurrent temporal patterns within a twenty-four hour period (Brittain & Eikeland, 1988). To ensure that as many organisms in drift as possible were captured the drift samplers were placed in the watercourse for twenty-four hours.

Preliminary drift sampling was undertaken at both sites on December 1996, to ascertain if the nets could be left for 24 hours without clogging. Thereafter, for five seasons: December 1996 (summer), March 1997 (autumn), June 1997 (winter), October 1997 (spring) and finally, February 1998 (summer).

Physicochemical parameters

In conjunction with the drift and benthic sampling, the air temperature, water temperature, dissolved oxygen levels, pH, and conductivity of the water at each site was recorded. The water temperature (°C) and dissolved oxygen levels (mg/L) were measured with a Yellow Springs 51B portable Dissolved Oxygen meter, pH was measured with a Watson-Victor model 5003, digital pH meter and conductivity (mS/cm) was measured with a Hanna conductivity meter, model HI 8733. Stream velocity was recorded when the drift nets were placed in the stream and before the nets were removed. Velocity was measured at the entrance of the net three times using an Ott velocity meter type 10 152, and a mean value was then calculated (m/sec).

Invertebrate identification and data analysis

Initially, benthic and drift invertebrate samples were sorted into taxonomic groups using an Olympus

SZ3060 dissecting microscope. Identification to species level was made, wherever possible, using published keys. Identifications of some groups were made using voucher specimens held at Deakin University (Burwood Campus), Victorian Rural Water Corporation (which became part of Melbourne Water's – Water ECOScience), or the Museum of Victoria. Chironomid larvae were processed for identification following the method described by Cranston (1990), using Hoyers mounting medium (Krantz, 1978) and examined with an Olympus CH compound microscope.

To determine whether there was a difference between the drift and benthic invertebrate fauna, a multivariate analysis was carried out using the software package PRIMER (Plymouth Routines in Multivariate Ecological Research Version 5.2.8). A non-metric multi-dimensional scaling procedure (NMDS) was applied using total species abundance for each benthic and both drift sites in Darebin Creek for all seasons, to generate an NMDS ordination and dendrogram. The procedure was carried out using a fourth root transformation of the species abundance to generate a Bray-Curtis similarity matrix.

Drift density and stream velocity

Drift densities were calculated as the number of invertebrates per cubic metre of water passing through the net during the sampling period. The mean current velocity measured at the beginning and end of the twenty-four hour period was used to calculate discharge. A one-way ANOVA was applied to the velocity data to determine if there was a significant difference in velocity between sites.

RESULTS

Table 1 contains a summary of measurements recorded at the time of benthic sampling in 1995, and drift sampling from summer 1997 until summer 1998. Generally, water chemistry at the two drift sampling sites on Darebin Creek was similar to that recorded at the benthic sites. The water was deeper at the first drift site (driftAD) with a median value of 40.5cm, compared to 29cm at the below drains site (driftBD). Conductivity decreased in a downstream direction with a mean of 2.12 mS/cm recorded at Site driftAD, and 1.44 mS/cm at Site driftBD, the reverse of what is usually found. A possible explanation is that the volume of stormwater entering the stream from three drains reduced the concentration of salts.

The velocity was consistently greater and varied more at the above drain drift site (driftAD) (Table 1). Site driftAD recorded a mean velocity of 0.19 m/sec compared to Site driftBD, with a mean of 0.04 m/

	Water temperature (°C)			Dissolved oxygen (mg/L)			Conductivity (mS/cm)			pH		
Darebin Creek – benthic sampling	*Site*			*Site*			*Site*			*Site*		
Summary data	1	3	5	1	3	5	1	3	5	1	3	5
mean	16.1	15.5	14.6	9.9	10.5	9.9	1.8	1.8	1.6	8.0	8.0	7.9
median	15.1	14.5	13.5	10.2	10.9	9.8	1.6	1.7	1.5	8.0	8.0	7.9
n	4	4	4	4	4	4	4	4	4	4	4	4

	Water temperature (°C)		Dissolved oxygen (mg/L)		Conductivity (mS/cm)		pH	
Darebin Creek – drift sampling	*Site*		*Site*		*Site*		*Site*	
Summary data	driftAD	driftBD	driftAD	driftBD	driftAD	driftBD	driftAD	driftBD
mean	16.8	16.8	16.1	15.5	2.1	1.4	8.2	8.2
median	17.5	17.0	10.3	8.7	2.2	1.4	8.2	8.2
n	12	12	12	12	11	11	12	12

Darebin Creek – drift sampling	Water depth (cm)		Mean velocity (m/sec)	
	Site		*Site*	
	driftAD	driftBD	driftAD	driftBD
mean	40.6	31.4	0.20	0.04
median	40.5	29.0	0.20	0.04
n	12	12	12	12

Table 1. Darebin Creek physicochemical summary data – measurements taken at the time of benthic sampling in 1995 at the above drain sites (upper table) and drift sampling in 1997–98 (lower table). Velocity was the only parameter with a significant difference ($p < 0.05$) between the drift site above the drains (drift AD) and below the drains (driftBD).

		summer 1995						*autumn 1995*					
Taxon	**Class/Order**	1	2	3	4	5	6	1	2	3	4	5	6
Austrochiltonia australis (Sayce, 1901)	**Amphipoda**	245	26	160	37	-	-	110	8	37	25	-	-
Sclerocyphon striatus Lea, 1895	**Coleoptera**	-	34	329	83	7	4	2	25	145	46	4	-
Chironomus cloacalis Martin, 1971	**Diptera**	7	565	2	5	1	17	1	-	4	-	-	-
Cricotopus sp.	**Diptera**	36	133	166	255	951	1629	102	127	56	70	20	189
Thienemanniella Cricotopus sp.A	**Diptera**	-	-	2	31	26	-	1	35	138	155	-	-
Physa acuta Draparnaud, 1805	**Gastropoda**	8	5	13	19	-	19	8	12	16	2	2	72
Heterias pusilla (Sayce, 1900)	**Isopoda**	26	62	71	-	-	-	390	33	491	10	-	-
Branchiura sowerbyi Beddard, 1892	**Oligochaeta**	11	37	15	4	7	-	15	67	1	10	126	29
Oligochaeta unidentified	**Oligochaeta**	255	836	425	280	141	1062	490	798	217	582	1858	1722
Ecnomus continentalis Ulmer, 1916	**Trichoptera**	10	234	243	320	22	11	29	4	26	9	-	-
Total invertebrate species		**15**	29	28	25	16	20	23	13	22	14	12	9
Total number of organisms		637	2191	1613	1170	1229	2829	1268	1175	1195	949	2042	2055

		winter 1995						*spring 1995*					
Taxon	**Class/Order**	1	2	3	4	5	6	1	2	3	4	5	6
Austrochiltonia australis	**Amphipoda**	57	18	56	115	-	-	13	34	-	-	1	8
Sclerocyphon striatus	**Coleoptera**	1	41	524	152	3	-	-	17	178	55	1	-
Chironomus cloacalis	**Diptera**	-	-	-	-	-	-	-	-	-	1	-	-
Cricotopus sp.	**Diptera**	44	138	81	140	108	294	55	116	157	84	79	969
Thienemanniella Cricotopus sp.A	**Diptera**	-	2.0	1.0	-	-	-	-	6	-	-	-	-
Physa acuta	**Gastropoda**	1	24	15	13	1	38	13	37	60	27	4	73
Heterias pusilla	**Isopoda**	735	610	255	45	1	-	545	154	606	63	8	-
Branchiura sowerbyi	**Oligochaeta**	12	147	14	39	44	42	17	26	2	4	66	3
Oligochaeta unidentified	**Oligochaeta**	570	3597	758	2205	409	1578	564	2026	560	1200	857	1707
Ecnomus continentalis Ulmer, 1916	**Trichoptera**	27	11	13	2	-	-	-	-	-	-	-	-
Total invertebrate species		**18**	23	22	17	18	**15**	**20**	**24**	23	**19**	**12**	**13**
Total number of organisms		1533	4742	1812	2828	617	2002	1326	2566	1826	1592	1153	2815

Table 2. Abundance of the ten most common invertebrates found in the benthos of Darebin Creek. Bold text indicates the dominant taxa for that season's benthic sampling. Sites 1, 3 and 5 were located above a stormwater drain and Sites 2, 4 and 6 below.

sec. A one-way ANOVA applied to the data indicated a significant difference ($p < 0.05$) between the mean velocity recorded at both sites.

Comparison of benthic and drift samples

Benthic and drift samples were collected in different years but many similarities in composition were evident in spite of this. The benthic samples taken from six sites on Darebin Creek in 1995 yielded sixty-three species from forty families and sixteen Orders (Veenstra-Quah, 2000). Drift samples collected from the two sites in 1997–8, yielded forty-eight species, (fifteen less than the benthos), from thirty families and fifteen Orders. The species richness in samples from both the benthos and drift was highest for the Order Diptera (27 species in the benthos and 20 species in drift), followed by Trichoptera (7 species in the benthos and 5 species in drift). Other groups found in both sample types included: Orders Hemiptera, Isopoda, Acarina, Amphipoda, as well as Classes Gastropoda and Oligochaeta.

A summary with abundance of the most common organisms collected from each site during the benthic study (Table 2) and the drift study (Table 3). Most benthic sites had at least eleven orders present with the exception of the site below the third stormwater drain Site 6 with invertebrates from only nine orders collected.

Site driftAD

The first drift site on Darebin Creek, Site driftAD above the stormwater drains, yielded thirty-two species, from twenty-three families and twelve Orders. The drift density ranged from 1 invertebrate/$m^3 \times 10^{-3}$ recorded in summer 1998, to 11 invertebrates/$m^3 \times 10^{-3}$ recorded in autumn and spring 1997; the mean drift density was 6 invertebrates/$m^3 \times 10^{-3}$.

Drift at the site above the stormwater drains (Site driftAD), was dominated by the orthoclad *Cricotopus* sp. during the summer 1997 (44 individuals), winter (16) and spring (114) periods (Table 3). Other taxa which contributed more than ten individuals were: the amphipod *Austrochiltonia australis* (Sayce, 1901) with 81 recorded in autumn, 4 in winter 1997 and 8 during the summer period 1998, *Chironomus cloacalis* Martin, 1971 with 36 in autumn plus 8 in summer 1998 and the trichopteran *Cheumatopsyche* sp. 2 with 24 recorded in autumn, 2 in summer 1997 and 1 individual in spring.

Site driftBD

The second drift site on Darebin Creek, below the stormwater drains (Site driftBD), yielded twenty-one species, from nineteen families and eleven Orders (Table 3).The drift density ranged from 3 invertebrates/$m^3 \times 10^{-3}$ recorded in autumn 1997, to 122 invertebrates/$m^3 \times 10^{-3}$ recorded in summer 1997; the mean drift density was 32 invertebrates/$m^3 \times 10^{-3}$.

Drift at this site was dominated by *Cricotopus* sp., during the summer (388 individuals), and spring 1997 (114) (Table 3). In autumn when only nine invertebrates were recorded, the drift was dominated by the surface dwelling hemipteran, *Microvelia* (2), and unidentified members of the family Tubificidae also with only 2 individuals. Another oligochaete, *Lumbriculus variegatus* (Müller, 1774) (14), *Microvelia* (8), and unidentified Hydracarina (6 individuals) were the dominant taxa in the winter period 1997. Mosquito larvae, *Aedeomyia venustipes* (Skuse, 1889) were also collected, with 2 in summer 1997, one in autumn 1997, 5 individuals in spring 1997 and 32 in summer 1998. *Lumbriculus variegatus* was also found in drift during the summer period 1997 with 5 individuals and 20 in summer 1998, while it was the most abundant invertebrate (14) in winter 1997.

Comparison of species composition between sites and sample types

In Darebin Creek, 78.9% of the taxa found in the benthos, upstream of the first drain (Site 1) occurred in the drift, while at the below drain drift site (driftBD), only 46.7% of the benthic taxa were found in the drift. The number of taxa common to both the benthos and drift also decreased in a downstream direction.

The orthoclad chironomid, *Cricotopus* sp. and unidentified oligochaetes were the taxa that may be considered typical of all six benthic sites, generally becoming increasingly abundant at the lower sites, and eventually dominating the invertebrate community at benthic sites associated with the third drain, Sites 5 and 6 (Veenstra-Quah, 2000). The drift was also dominated by this chironomid at both sites in summer 1997 and 1998 plus spring 1997, and at the above drain site only in the winter 1997 collection. However, unidentified worms did not dominate the drift with comparatively low numbers of the introduced worm *Lumbriculus variegates,* being collected

		summer 1997		*autumn 1997*		*winter 1997*		*spring 1997*		*summer 1998*	
Taxon	**Class/Order**	**driftAD**	**driftBD**	**driftAD**	**driftBD**	**driftAD**	**driftBD**	**driftAD**	**driftBD**	**driftAD**	**driftBD**
Hydracarina	**Acarina**	-	2	2	-	-	6	-	1	-	2
Austrochiltonia australis (Sayce, 1901)	**Amphipoda**	1	-	81	-	4	-	2	-	8	-
Aedeomyia venustipes (Skuse, 1889)	**Diptera**	-	2	-	1	-	-	-	5	-	32
Chironomus cloacalis Martin, 1971	**Diptera**	-	3	36	-	1	-	-	-	8	-
Cricotopus sp.	**Diptera**	44	388	21	-	16	1	114	15	5	12
Psychodidae sp.1	**Diptera**	-	-	-	-	-	-	-	-	-	8
Thienemanniella sp. A	**Diptera**	8	-	-	-	-	-	4	-	1	-
Tipilidae sp.1	**Diptera**	-	1	-	1	-	-	-	-	-	-
Agraptocorixa sp.	**Hemiptera**	1	-	1	-	-	-	-	-	5	-
Microvelia sp.	**Hemiptera**	-	2	-	2	3	8	1	-	1	-
Heterias pusilla (Sayce, 1900)	**Isopoda**	12	-	-	-	1	1	3	-	-	-
Lumbriculus variegatus (Muller)	**Oligochaeta**	-	5	1	-	5	14	5	-	-	20
Tubificidae unidentified	**Oligochaeta**	-	3	-	2	-	-	-	-	-	-
Hydroptila losida Mosely, 1953	**Trichoptera**	-	-	-	-	3	-	-	-	5	-
Cheumatopsyche sp.2	**Trichoptera**	2	-	24	-	-	-	1	-	-	-
Total invertebrate species		**11**	**12**	**19**	**7**	**10**	**5**	**7**	**3**	**15**	**16**
Total number of organisms		81	413	239	9	40	31	134	21	55	90

Table 3. Abundance of the fifteen most common invertebrates found in the drift in Darebin Creek. Bold text indicates the dominant taxa for that season's drift sampling. Site located above stormwater drains is driftAD and Site driftBD below drains.

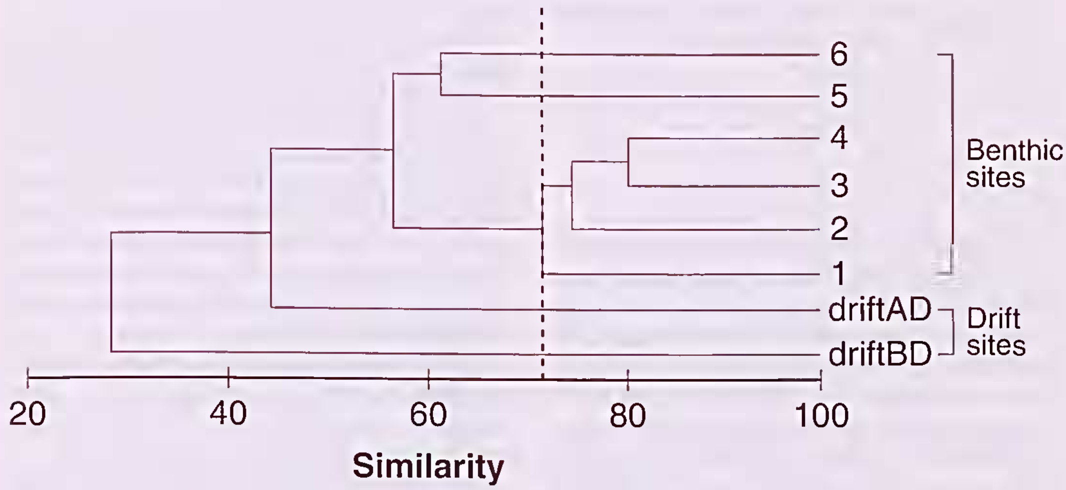

Fig. 2a. Dendrogram for drift sites (driftAD and driftBD), and benthic Sites 1, 3 and 5 = above a drain; Sites 2, 4 and 6 = below a drain), using group-average clustering from Bray-Curtis similarities on fourth root transformed abundances. The two drift sites and all benthic sites separated at a 71% similarity threshold (broken line).

from both drift sites. *Sclerocyphon striatus* Lea 1895 (Coleoptera: Psephenidae) and the trichopteran *Economus continentalis* Ulmer 1916 were collected from the benthos at the majority of sites during the summer 1995 (Table 2) but were not found in drift.

An NMDS two dimensional ordination plot and associated dendrogram, was generated using the pooled replicates of benthic samples, and the seasonal drift fauna from each site (Figs. 2a, 2b).

The stress value for the ordination was less than 0.05 indicating an excellent representation with no prospect of misinterpretation (Clarke, 1993) of the relationship between the drift and benthic sites. When the associated dendrogram is examined, at a 71% similarity threshold the two drift sites are clearly separated from each other and from all benthic sites. The plot with superimposed clusters shows that the benthic sites most closely associated are Sites 2, 3

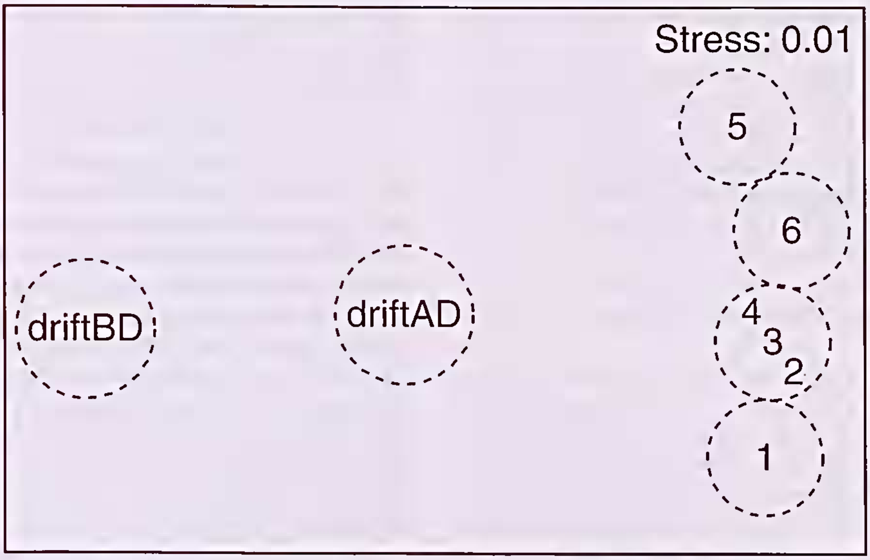

Fig. 2b. Non-metric multi-dimensional scaling ordinations for Darebin Creek drift and benthic sites with superimposed clusters from the associated dendrogram at a similarity level of 71% (broken line).

and 4, while Sites 1, 5 and 6 appear to be separated from each other and all other benthic sites.

DISCUSSION

Limitations

A major limitation of this study is that the drift and benthic samples were collected in different years. However the impact of discharges from housing, the surrounding industries and sewer overflows on the in-stream biota are presumably large and persistent. Therefore benthic sample data are presented to aid the understanding of the composition of drift samples and their possible origin. Clearly there were habitat differences, particularly water velocity, between the two drift sites potentially having a significant effect on the composition of the fauna collected.

A suction sampler was chosen for the Darebin Creek benthic study (Veenstra-Quah, 2000), because it was independent of current, and reported to be quantitatively superior when sampling a variety of substrates (Boulton, 1985). However, the overwhelming abundance of oligochaetes (over 1000 worms in many samples) in the benthic samples suggests that the suction sampler increased the number of burrowing animals collected thereby biasing the collection (pers. obs.), this may further explain the differences between the drift (with a maximum of 20 oligochaetes) and benthic samples in this study.

The routine recording of water chemistry parameters at the drift sampling sites may be of limited value as it is the physicochemical status of the water upstream from where the invertebrates enter the drift, which influences their behaviour. However, any dramatic changes in water quality recorded at the time of drift sampling may have been useful when interpreting the drift composition and density.

Relationship of drift with the benthos

The biota of urban streams like Darebin Creek, must cope with a variety of natural and imposed stresses such as chemical loading in stormwater runoff from managed land (Klein, 1979; Poff & Ward, 1989; 1990; Walsh, 2004; Walsh et al., 2001), heavy metals and nutrients from sewage outfalls (Duke & Veenstra-Quah, 1997), frequent peak flow events with their high hydraulic forces (Lancaster et al., 1996), increased sedimentation from urban and agricultural erosion (Brooks & Brierley, 1997; Olsen et al., 2007), temperature increase associated with increased solar radiation (Collier, 1995), and alteration of channel structure (Lamberti & Berg, 1995).

The non-metric multi-dimensional scaling plot and associated dendrogram using drift and benthic invertebrate abundance data from Darebin Creek demonstrated a clear distinction between the drift and benthic samples. The invertebrates found at the benthic sites prior to the drift study showed little variation over the course of the twelve month study, so it is unlikely that the differences indicated in the plot are due to temporal effects. The two drift sites also appear to be clearly separated from each other due to the greater diversity of invertebrate species at Site driftAD (32 species) compared with a total of 21 species at the site downstream of the drains. A problem with the study of invertebrate drift that remains unresolved is that the distance travelled has never been ascertained so the source of the invertebrates is difficult to pinpoint.

Veenstra-Quah (2000) found that at the benthic sites in Darebin Creek invertebrates known to be associated with stressed environments such as *Chironomus cloacalis* Martin 1971, *Cricotopus* sp. and oligochaetes (Wright et al., 1995) increased in abundance while the less pollution tolerant ephemeropterans, and trichopterans declined. A similar pattern of invertebrate distribution has been reported in studies of urban streams in the northern hemisphere (Klein, 1979; Whiting & Clifford, 1983; Jones & Clark, 1987; Tate & Heiny, 1995). A predominance of chironomids and oligochaetes in the benthos can also characterise a stream reach affected by organic pollution (McIvor, 1976; Campbell, 1978; Arthington et al., 1982; Wiederholm, 1984; Wright et al., 1995). The water quality data recorded during the study by Duke & Veenstra-Quah (1997) indicated nutrient enrichment, which may favour the proliferation of some pollution tolerant invertebrate species such as *Cricotopus* sp., *Chironomus* spp., or oligochaetes.

An increased number of the amphipod *Austrochiltonia australis* was found at the above drains drift site (driftAD), in the wetter seasons of autumn 1997, and summer 1997–8 suggesting that they may have been dislodged from the substrate by force of the current. Few hemipterans were found in the drift at either site, perhaps because of the lower rainfall recorded over the course of the study, and their low abundance in the benthos (Veenstra-Quah, 2000). Mosquito larvae, *Aedeomyia venustipes*, usually associated with a lentic environment were consistently found in the drift at Site driftBD after rainfall in autumn and spring of 1997, as well as summer 1997–8. This invertebrate was not found at any site in the benthic samples collected in 1995. *Aedeomyia venustipes* larvae are found throughout the year (Dobrotworsky, 1965), so their abundance in drift during these seasons was probably not related to their life cycle. It is likely that they were washed in from pool areas upstream of the drift site.

Members of the genus *Cricotopus* are primarily tube dwellers, but this day-active genus (Cadwallader & Eden, 1977) may have deliberately entered the drift. *Cricotopus* sp. dominated the drift at both sites in the summer and spring of 1997 and the above drain Site driftAD in the winter 1997. Their abundance in the drift did not always coincide with increased rainfall and a consequent increase in flow.

Other reasons for this increased abundance of *Cricotopus* sp. in the drift may include unsuitable habitat conditions (Bishop & Hynes, 1969; Lake et al., 1977; Swain & White, 1985; Davies et al., 1994), population pressure providing a stimulus for dispersal (Hieber et al., 2003), or life cycle stage, with periods of maximum drift coinciding with periods of maximum growth in the spring and summer (Brittain & Eikeland, 1988). The higher temperatures (Reisen & Prins, 1972), and longer daylight hours (Cadwallader & Eden, 1977), in spring and summer may also have resulted in increases in the drift.

Wilzbach & Cummins (1989) found that the mortality of drifting invertebrates was three-fold that of the benthic fauna, and Minshall & Petersen (1985), suggested that drifting invertebrates may be less fit than non-drifters. There is a possibility that some chironomids found in the drift in Darebin Creek were less fit than their benthic counterparts.

The introduced oligochaete *Lumbriculus variegatus* was always more abundant at the below drain drift site, but was found at both drift sites in winter 1997, and not found in the wetter seasons of autumn and spring 1997. Unidentified oligochaetes dominated the benthos at many of the sites upstream of Site driftBD suggesting that the presence of *Lumbriculus variegatus* in the drift may be due to factors such as high population density and pressure to find a new habitat rather than accidental dislodgment.

There are a number of factors that could possibly be reducing the benthic invertebrate diversity in Darebin Creek. These factors include: increased imperviousness of the catchment (Walsh 2004; Walsh et al., 2001) channelization, particularly when the channel is straightened leaving little or no riparian zone vegetation to provide habitat for adult insects (Collier & Smith, 1997; Collier et al., 1998; Collier et al., 2000; Collier, 2001), and to act as a regulator of water temperature, light, seepage, and nutrient transfer (Boon, 1992), urban runoff plus sewage spills containing heavy metals and nutrients that are also detrimental to stream invertebrate diversity.

The stream velocity was significantly higher ($p < 0.05$) at the above drain drift site (driftAD) but the mean drift density was greater at the site below the drains site (driftBD). The presence of pollutants including heavy metals in the stream (Duke & Veenstra-Quah, 1997) may have discouraged invertebrates from exiting the drift to colonise the region downstream of the stormwater drains, which may explain the higher mean drift density recorded at Site driftBD.

The decline in the total number of species in the drift was indicative of something impacting the benthic fauna upstream of the drift sampling point or the interplay of a number of factors. One problem is that the origin of the drifting fauna is not known and difficult to ascertain. In the Northern hemisphere, invertebrates are not thought to drift very far in small, stony streams, where they tended to settle back into a safe refuge in a short time (Allan & Feifarek, 1989). A typical drift distance was considered to be about 10 m, although distances of 100 m or more have been reported (McLay, 1970). Benke et al. (1986) found that invertebrates dislodged from their snag habitat appeared to drift for long distances (0.18–1.8 km), much further than had been observed in most small streams.

Lancaster et al. (1996) found that the physical habitat influenced the distances drifted by dislodged invertebrates. The total distances that organisms move downstream in the drift has not been studied extensively (Allan, 1995). In Australian urban streams, with their channel modifications and high influx of urban runoff, the distances travelled by invertebrates via the drift may be far greater than those recorded in less disturbed streams in the Northern hemisphere.

Use of drift in biomonitoring

The proposed advantages of drift over benthic sampling include the relative ease of collection and sorting of drift samples, as well as the possibility that only a few drift samples may be needed to represent the benthos (Arthington et al., 1982). Wilzbach et al.

(1988) stated that the drift could be used as an indicator of disturbed conditions. Their reasoning being that animals usually found crawling on or burrowing into the substrate are unlikely to occur in the water column, except as a result of a change in life history stage, by accident, or under abnormal conditions such as their habitat suddenly becoming intolerable, water-borne transport may be the quickest means of escape (Wilzbach et al., 1988).

Although drift is not a simple index of the benthos that generates it (Elliott & Minshall, 1968; Tilley, 1989), some investigators have reported a general resemblance between the drift and the benthos (Tilley, 1989; Hieber et al., 2003), while others have observed that taxa found in the benthos differed from that of the drift (Cowell & Carew, 1976; Dudgeon, 1983; Benke et al., 1986; Koetsier & Bryan, 1996; Bergey & Ward, 1989; Schreiber, 1995b). Based on the results of the drift and benthic studies of Darebin Creek and Dandenong Creek (Veenstra-Quah, 2000) there appear to be similarities between the taxa found in the drift and upstream benthos. This concurs with Arthington et al. (1982) who found that only the relative proportions of taxa were different in the samples collected from the drift and the benthos of Bulimba Creek in Queensland, Australia.

The sampling of drift does not always give a good indication of the status of the benthos (Statzner et al., 1987). If drift samples are to be successfully used as proxy measures of the benthic community and indicators of water quality, an improved understanding of the ecology of individual species, and all of the factors that affect their presence in the drift must be attained (Tilley, 1989).

Sampling both the drift and benthos of Darebin Creek gives a more complete assessment of the invertebrate fauna (Collier, 2001). Similar conclusions were reached in a study undertaken by Arthington et al. (1982), where some taxa e.g. Hydracarina, were more abundant in the drift than the benthos, and conversely, the oligochaetes which dominated the benthos in Darebin Creek were found in comparatively low numbers in the drift. The results of this study support the view of Pringle & Ramírez, (1998) who advocated the use of drift samples to complement direct sampling of the benthos for biological assessment of streams, as they can provide additional information on taxon richness.

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REFERENCES

Allan, J.D., 1995. *Stream Ecology: Structure and Function of Running Waters*. Chapman & Hall, London, 404pp.

Allan, J.D. & Feifarek, B.P.G., 1989. Distances travelled by drifting mayfly nymphs: factors influencing return to the substrate. *Journal of the North American Benthological Society* 8: 322–330.

Arthington, A.H. & Conrick, D.L., 1981. Alternative approach to biological monitoring: sampling stream drift. *Australian Society for Limnology Newsletter* 19: 14.

Arthington, A.H., Conrick, D.L. Connell, D.W. & Outridge, P.M., 1982. The Ecology of a Polluted Urban Creek. *Australian Water Resources Council Technical Paper* No. 68. (AWRC: Canberra).

Benke, A.C., Hunter, R.J. & Parrish, F.K., 1986. Invertebrate drift dynamics in a subtropical blackwater river. *Journal of the North American Benthological Society* 5: 173–190.

Benson, L.J. & Pearson, R.G., 1987. The role of drift and effect of season on macroinvertebrate colonisation of implanted substrata in a tropical Australian stream. *Freshwater Biology* 18: 109–116.

Bergey, E.A. & Ward, J.V., 1989. Upstream-downstream movements of aquatic invertebrates in a Rocky Mountain stream. *Hydrobiologia* 185: 71–82.

Bishop, J.E. & Hynes, H.B.N., 1969. Downstream drift of the invertebrate fauna in a stream ecosystem. *Archiv für Hydrobiologie* 66: 56–90.

BOON, P.J., 1992. Essential elements in the case for river conservation. In: *River Conservation and Management*, P.J.Boon, P. Calow, & G.E. Petts,. eds, John Wiley & Sons Ltd., Chichester, 24.

BOULTON, A.J., 1985. A sampling device that quantitatively collects benthos in flowing or standing waters. *Hydrobiologia* 127: 31–39.

BRITTAIN, J.E. & EIKELAND, T.J., 1988. Invertebrate drift – a review. *Hydrobiologia*, 166: 77–93.

BROOKS, A.P. & BRIERLEY, G.J., 1997. Geomorphic responses of the lower Bega River to catchment disturbance, 1851–1926. *Geomorphology* 18: 291–304.

CADWALLADER, P.L. & EDEN, A.K., 1977. Effect of a total solar eclipse on invertebrate drift in Snobs Creek, Victoria. *Australian Journal of Marine and Freshwater Research* 28: 799–805.

CAMPBELL, I.C., 1978. A biological investigation of an organically polluted urban stream in Victoria. *Australian Journal of Marine and Freshwater Research* 29: 275–291.

CLARKE, K.R., 1993. Non-parametric multivariate analysis of changes in community structure. *Australian Journal of Ecology* 18:117–143.

COLLIER, K.J., 1995. Environmental factors affecting the taxonomic composition of aquatic macroinvertebrate communities in lowland waterways of Northland, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 29: 453–465.

COLLIER, K.J., 2001. Measuring stream invertebrate biodiversity. *Water and Atmosphere* 9: 14–15.

COLLIER, K.J. & SMITH, B.J., 1997. Dispersal of adult caddisflies (Trichoptera) into forests alongside three New Zealand streams. *Hydrobiologia* 361: 53–65.

COLLIER, K.J., SMITH, B.J. & BAILLIE, B.R., 1998. Summer light-trap catches of adult Trichoptera in hill-country catchments of contrasting land use, Waikato, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 31: 623–634.

COLLIER, K.J., SMITH, B.J., QUINN, J.M., SCARSBROOK, M.R., CROKER, G.F. & PARKYN, S. M., 2000. Biodiversity of stream invertebrate faunas in a Waikato hill-country catchment in relation to land use. *New Zealand Entomologist* 23: 9–22.

COWELL, B.C. & CAREW, W.C., 1976. Seasonal and diel periodicity in the drift of aquatic insects in a subtropical Florida stream. *Freshwater Biology* 6: 587–594.

CRANSTON, P.S., 1990. Keys to the Australian Chironomidae. In *Proceedings from Murray-Darling Freshwater Research Centre Taxonomy Workshop. 19–20 February 1990*. (unpublished)

DAVIES, P.E., COOK, L.S.J. & BARTON, J.L., 1994. Triazine herbicide contamination of Tasmanian streams: sources, concentrations and effects on biota. *Australian Journal of Marine and Freshwater Research* 45: 209–226.

DIMOND, J.B., 1967. Evidence that drift of stream benthos is density related. *Ecology* 48(5): 855–857.

DOBROTWORSKY, N.V., 1965. *The Mosquitoes of Victoria*: Diptera, Culicidae. Melbourne University Press, Carlton, 246pp.

DOEG, T.J. & MILLEDGE, G.A., 1991. Effect of experimentally increasing concentrations of suspended sediment on macroinvertebrate drift. *Australian Journal of Marine and Freshwater Research* 42: 519–526.

DOUGLAS, J.G. & FERGUSON, J.A. (eds)., 1976. *Geology of Victoria*. Geological Society of Victoria Special Publication No.5, Melbourne, 665pp.

DUDGEON, D., 1983. An investigation of the drift of aquatic insects in Tai Po Kau Forest stream, New Territories, Hong Kong. *Archiv für Hydrobiologie* 96(4): 434–447.

DUDGEON, D., 1990. Seasonal dynamics of invertebrate drift in a Hong Kong stream. *Journal of Zoology*, London 222: 187–196.

DUKE, G. & VEENSTRA-QUAH, A.A., 1997. *Development of a bioindicator to measure instream effects of wastewater overflows ñ final report*. Applied Australian Ecological Research Unit: Deakin University.

ELLIOTT, J.M. & MINSHALL, G.W., 1968. The invertebrate drift in the River Duddon, English Lake District. *Oikos* 19: 39–52.

FLECKER, A.S., 1992. Fish predation and the evolution of invertebrate drift periodicity: evidence from neotropical streams. *Ecology* 73: 438–448.

GRAESSER, A. & LAKE, P.S., 1984. Diel changes in the benthos of stones and of drift in a southern Australian upland stream. *Hydrobiologia* 111: 153–160.

HIEBER, M., ROBINSON, C.T. & UEHLINGER, U., 2003. Seasonal and diel patterns of invertebrate drift in different alpine stream types. *Freshwater Biology* 48: 1078–1092.

HOLOMUZUKI, J.R., 1996. Effects of substrate and predator type on microdistributions and drift of a lotic mayfly. *Journal of the North American Benthological Society* 15(4): 520–528.

JONES, R.C. & CLARK, C.C., 1987. Impact of watershed urbanization on stream insect communities. *Water Resources Bulletin* 23: 1047–1055.

KLEIN, R.D., 1979. Urbanization and stream quality impairment. *Water Resources Bulletin* 15: 948–963.

KOETSIER, P. & BRYAN, C.F., 1989. Winter and spring invertebrate drift in an outpocketing of the lower Mississippi River, Louisiana (USA). *Hydrobiologia* 185: 205–209.

KOETSIER, P. & BRYAN, C.F., 1996. Is macroinvertebrate drift a density-dependent mechanism of the benthos in the Lower Mississippi River? *Journal of Freshwater Ecology* 11: 1–10.

KRANTZ, G.W., 1978. A Manual of Acarology. 2nd edition, Corvallis, Oregon State University Bookstores: USA.

LAKE, P.S., COLEMAN, D., MILLS, B. & NORRIS, R., 1977. A reconnaissance of pollution of the King River in the Comstock and Crotty area, western Tasmania. In: *Landscape and Man. Symposium of the Royal Society of Tasmania*, November 1976, Hobart 157–173.

LAMBERTI, G.A. & BERG, M.B., 1995. Invertebrates and other benthic features as indicators of environmental change in Juday Creek, Indiana. *Natural Areas Journal* 15: 249–258.

LANCASTER, J., HILDREW, A.G. & GJERLOV, C., 1996. Invertebrate drift and longitudinal transport processes in streams. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 572–582.

MCIVOR, C.C., 1976. The effects of organic and nutrient enrichment on the benthic macroinvertebrate community of Moggill Creek, Queensland. *Water*, 3: 16–21

MCLAY, C.L., 1968. A study of drift in the Kakanui River, New Zealand. *Australian Journal of Marine and Freshwater Research* 19: 139–149.

MCLAY, C., 1970. A theory concerning the distances travelled by animals entering the drift of a stream. *Journal of the Fisheries Research Board of Canada* 27: 359–370.

MELBOURNE WATER – CATCHMENT AND DRAINAGE, 1998. *Stream Health Assessment Review Paper: Stream Health Discussion of the Darebin Creek Catchment*, Melbourne Water: Melbourne.

MINSHALL, G.W. & PETERSEN, R.C. Jr., 1985. Towards a theory of macroinvertebrate community structure in stream ecosystems. *Archiv für Hydrobiologie* 104: 49–76.

NORTHERN MELBOURNE WATERWAYS STUDY, 1975. Preston Institute of Technology, Preston, Bundoora. pp 226.

OLSEN, D.A., MATTHAEI, C.D., & TOWNSEND, C.R., 2007. Patch history, invertebrate patch dynamics and heterogeneous community composition: perspectives from a manipulative stream experiment. *Marine and Freshwater Research*, 58: 307–314.

POFF, N.L. & WARD, J.V., 1989. Implications of streamflow variability and predictability for lotic community structure: A regional analysis of streamflow patterns. *Canadian Journal of Fisheries and Aquatic Sciences* 46: 1805–1818.

POFF, N.L. & WARD, J.V., 1990. Physical habitat template of lotic systems: recovery in the context of historical pattern of spatiotemporal heterogeneity. *Environmental Management* 14: 629–645.

PRINGLE, C.M. & RAMÍREZ, A., 1998. Use of both benthic and drift sampling techniques to assess tropical stream invertebrate communities along an altitudinal gradient, Costa Rica. *Freshwater Biology* 39: 359–373.

REISEN, W.K. & PRINS, R., 1972. Some ecological relationships of the invertebrate drift in Praters Creek, Picken County, South Carolina. *Ecology* 53: 876–885.

RESH, V.H. & MCELRAVY, E.P., 1993. Contemporary quantitative approaches to biomonitoring using benthic macroinvertebrates. In: *Freshwater Biomonitoring and Benthic Macroinvertebrates*, D. M. Rosenberg, & V.H. Resh, eds, Chapman & Hall: New York, 159–194.

SCHREIBER, E.S.G., 1988. Seasonal and Diel Variations in Macroinvertebrate Drift in a Temperate Australian Upland Stream.

Unpublished MSc thesis Monash University, Melbourne.

SCHREIBER, E.S.G., 1995a. Long-term patterns of invertebrate stream drift in an Australian temperate stream. *Freshwater Biology* 33: 13–25.

SCHREIBER, E.S.G., 1995b. Stream drift of Chironomidae: Diel and seasonal patterns in the Acheron River, Victoria, Australia. In: *Chironomids: From genes to ecosystems,* P.S. Cranston, ed., CSIRO, Australia, 205–211.

STATZNER, B., ELOUARD, J-M. & DEJOUX, C., 1987. Field experiments on the relationship between drift and benthic densities of aquatic insects in tropical streams (Ivory Coast). III Trichoptera. *Freshwater Biology* 17: 391–404.

SUTER, P.J. & WILLIAMS, W.D., 1977. The effect of a total solar eclipse on stream drift. Australian Journal of Marine and *Freshwater Research* 28: 793–798.

SWAIN, R. & WHITE, R.W.G., 1985. Influence of a metal-contaminated tributary on the invertebrate fauna of the King River (Tasmania, Australia). *Hydrobiologia* 122: 261–266.

TATE, C.M. & HEINY, J.S., 1995. The ordination of benthic invertebrate communities in the South Platte River basin in relation to environmental factors. *Freshwater Biology* 33: 439–454.

THEXTON, E., 1986. The northern waterways program. *Trees and Natural Resources*, 28: 13–14.

TILLEY, L.J., 1989. Diel drift of Chironomidae larvae in a pristine Idaho mountain stream. *Hydrobiologia* 174: 133–149.

TOWNSEND, C.R. & HILDREW, A.G., 1976. Field experiments on the drifting, colonisation and continuous distribution of stream benthos. *Journal of Animal Ecology* 45: 759–772.

VEENSTRA -QUAH, A.A., 2000. The Impact of Stresses Imposed on Macroinvertebrate Communities in Two Urban Streams. Unpublished PhD thesis. Deakin University.

WALSH, C.J., 2004. Protection of in-stream biota from urban impacts: minimise catchment imperviousness or improve drainage design? *Marine and Freshwater Research*, 55: 317–326.

WALSH, C.J., SHARPE, A.K., BREEN, P.F. & SONNEMAN, J.A., 2001. Effects of urbanisation of streams of the Melbourne region, Victoria, Australia I. Benthic macroinvertebrate communities, *Freshwater Biology.* 46: 535–551.`

WIEDERHOLM, T., 1984. Responses of aquatic insects to environmental pollution. In: *The Ecology of Aquatic Insects* edited by V.H. Resh, & D.M. Rosenberg, eds., Praeger Publishers: New York, 508–557.

WHITING, E.R. & CLIFFORD, H.F., 1983. Invertebrates and urban runoff in a small northern stream, Edmonton, Alberta, Canada. *Hydrobiologia* 102: 73–80.

WILZBACH, M.A. & CUMMINS, K.W., 1989. An assessment of short-term depletion of stream macroinvertebrate benthos by drift. *Hydrobiologia* 185: 29–39.

WILZBACH, M.A., CUMMINS, K.W. & KNAPP, R.A., 1988. Toward a functional classification of stream invertebrate drift. *Verhandlungen der InternationaleVereinigung für Theoretische und Angewandte Limnologie* 23: 1244–1254.

WRIGHT, I.A., CHESSMAN, B.C., FAIRWEATHER, P.G. & BENSON, L.J., 1995. Measuring the impact of sewage effluent on the macroinvertebrate community of an upland stream: The effect of different taxonomic resolution and quantification. *Australian Journal of Ecology* 20: 142–149.